VU Research Portal

Climate and Tectonic Influence on Alluvial Dynamics in the Weihe Basin, Central China

Rits, D.S.

2017

document version
Publisher's PDF, also known as Version of record

Link to publication in VU Research Portal

citation for published version (APA)
Rits, D. S. (2017). *Climate and Tectonic Influence on Alluvial Dynamics in the Weihe Basin, Central China*. [PhD-Thesis - Research and graduation internal, Vrije Universiteit Amsterdam].

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal ?

Take down policy
If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

E-mail address:
vuresearchportal.ub@vu.nl

Download date: 04. May. 2023

2

Setting

2.1 Geographical setting

Core LYH was drilled along the northern margin of the Weihe Basin, near the city of Pucheng at an altitude of approximately 370-380 m.a.s.l. The area is a wetland complex and comprises many swamps and ponds. Soils in the wetland have low permeability and are highly saline, which makes the region subject to extensive salt mining. Local industry extracts sodium sulfate from salt pans, irrigated by ground water, which is pumped from-depths of 30-50 m (Kong et al., 2013a).

The Weihe Basin is an elongated, WSW-ENE trending rift basin in Central China and forms the southern half of the arch-shaped Fenwei Graben (Fig. 1.1c). The Weihe Basin is bordered in the South by the Qinling Mountains and in the North by the Central Loess Plateau (CLP), which covers the stable Ordos Block (Fig. 1.1b). The NNW-SSE orientated Liupan Mountain marks the western margin of the basin while the canyons of the Sanmen Gorge are located along the eastern margin. This gorge marks the boundary between important tectonic-geomorphic units in mainland China. To the northeast of the Weihe Basin are the N-S trending Luliang and Tailing Mountains, which mark the eastern boundary of the Fenhe Basin (the northern half of the Fenwei Graben). The Weihe Basin covers an approximate area of 25000-30000 km^2 (Fig. 1.1c) and stretches out from the cities of Baoji in the West to Sanmenxia in the East.

The most prominent feature of the basin are the steep cliffs on the northern and southern borders. The Qinling Mountains in the south have a mean altitude of 2000 m.a.s.l. and the Beishan Mountain is with an altitude of over 1000 m.a.s.l. the highest peak that marks the northern boundary. This mountain is also the most proximal to core LYH. In addition to the mountains at the basin margin, there are several other mountain peaks that rise from the basin floor. The Lishan Mountain, near Xi'an, reaches an altitude of 850 m.a.s.l., while the Zhongtiao Mountain and Emei Platform in the East reach altitudes of 1000 and 700 m.a.s.l. respectively. In contrast, the central part of the Weihe Basin is with 320-350 m.a.s.l., significantly lower.

2.2 Geological and tectonic setting

2.2.1 Geology

Figure 2.1a shows the geological map of the Weihe Basin and its surroundings. To the north of the basin is the Ordos Block, which is largely covered with Quaternary sediments. This is the result of widespread deposition of eolian dust, which began to accumulate since Early Miocene (Guo et al., 2002), but witnessed an accelerated accumulation rate at the onset of the Quaternary ice ages (An et al., 2001). Only in some river valleys, the underlying Mesozoic (and in some cases Neogene) strata are exposed. As a result of the rifting, the Beishan Mountain, as well as other bordering mountains between the Ordos Block and the Weihe Basin were uplifted (Wang, 1987). This resulted in exposure of Early and Late Paleozoic limestones. The Weihe Basin is almost entirely covered with Quaternary loess and alluvial deposits. Only the Lishan Mountain in the south and the Zhongtiao Mountain and Emei Platform in the East have outcrops of older sediments. To the south of the basin are the Qinling Mountains. The crustal thickening along the mountain front resulted in uplift of older rocks. Bedrock units exposed by the Qinling orogen include Archean crystalline basement, overlain by a series of Proterozoic metamorphic rocks and sedimentary strata from the Palaeozoic and Mesozoic times. This sequence has been intruded by 152-135 Ma granitoid plutons (Liu et al., 2013).

2.2.2 Tectonic evolution

The rift basin is as an active basin, having witnessed several large earthquakes (Ms > 7.0) over the last few centuries (Liu et al., 2013). The Huaxian great earthquake in 1556 even reached a magnitude of Ms ~8.5 and caused more than 830,000 deaths (Rao et al., 2014).

The development of the Weihe Basin is controlled by its southern and northern boundary faults (Zhang et al., 1995; 1998; 2003). The southern boundary fault (Huashan-Qinling piedmont fault) extends east-west over a distance that exceeds 310 km from Baoji to Tongguan. It is the largest and most active fault zone in the area and hence plays a vital role in shaping the Weihe Basin. The most important faults to the north of the basin are the Qishan-Mazhao Fault (QMF), the Kouzhen-Guanshan Fault (KGF), Beishan Piedmont Fault (BPF), and the Hancheng Fault (HSF). The Weihe Fault (WF) strikes through the center of the basin (Fig. 2.1a). For an overview of the major faults in Central China, see Figure 2.2a.

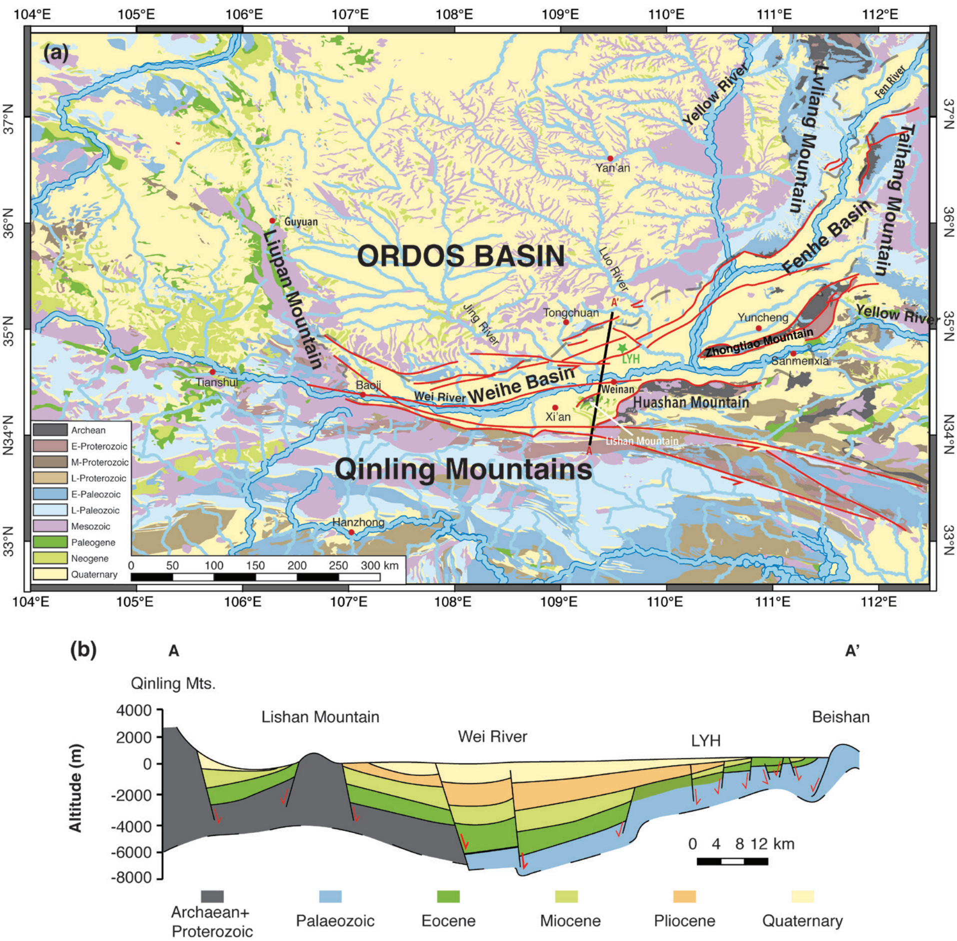

Figure 2.1 - (a) Geologic map of the area surrounding the Fenwei Graben. The most important faults regarding the this basin are drawn in. The map is modified after a geological map from the Institute of Geology, Chinese Academy of Geological Sciences. **(b)** A north-south cross profile through the Weihe Basin (modified after Wang (1987); see for location fig. 2.1a).

Tectonic motions are strongest along the southern margin of the basin, which gives the basin an asymmetric configuration (Fig. 2.1b). This results in a northward thinning trend of Cenozoic deposits in the Weihe Basin. The deposits in the South can reach up to 7000 m thickness, but in the northern margin this is only 2000 m. Since the onset of the Quaternary, the sedimentation rates in the basin drastically increased from an average of about 8 cm/kyr to 47 cm/kyr, which might indicate increased tectonic offset between the basin and its surroundings (Sun, 2005).

The formation of the Weihe Basin is strongly related to the orogen of the Qinling Mountains and the formation of the Tibetan Plateau. The Qinling Mountains mark the boundary between the South China Block (SCB) and the North China Block (NCB) (Fig. 2.2b). Continued northward movement of the SCB eventually led to continent-continent obliquely diachronous

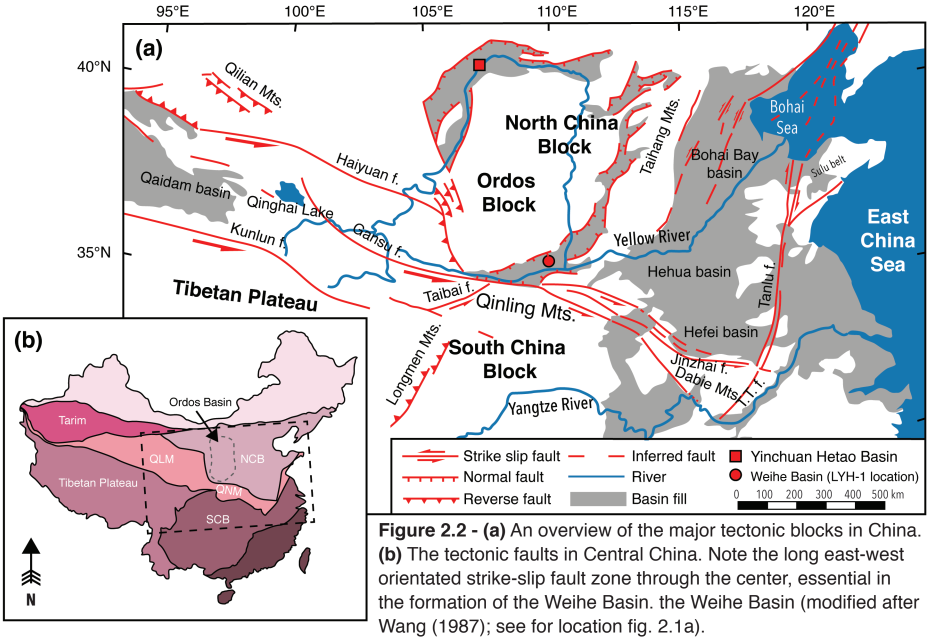

Figure 2.2 - (a) An overview of the major tectonic blocks in China. **(b)** The tectonic faults in Central China. Note the long east-west orientated strike-slip fault zone through the center, essential in the formation of the Weihe Basin. the Weihe Basin (modified after Wang (1987); see for location fig. 2.1a).

collision at the Early Mesozoic (Liu et al., 2013). The intracontinental shortening produced major thrust faults, which extends into the area that currently comprises the position of the Weihe Basin (Wang, 1987). During Eocene times, the tectonic stress field changed from a compressional to an extensional regime. The thrust faults transformed into normal faults along which the Weihe Basin started to subside (Zhang et al., 2003). Strike–slip and normal faults associated with Eocene half-graben basins (Figure 2.1b) record Cenozoic NNE–SSW contraction and WNW–ESE extension (Ratschbacher et al., 2003). The tectono-sedimentary evolution indicates three extension episodes, associated with large-scale subsidence and the development of 3 fault blocks (Weihe-, Lishan-, Qinling fault blocks) (Zhang et al., 1995; 1998). The first period of extension occurred from Middle Eocene to Early Oligocene, the second from Middle to Late Miocene (Zhang et al., 2003). An accelerated phase of subsidence in the Weihe Basin may have occurred at approximately 7.3 Ma (Liu et al., 2013).

The reason for the transformation to large-scale rifting around the Ordos Block is commonly attributed to the eastward extrusion of South China as a result of several tens of kilometers of post-Eocene left-lateral displacement along the Haiyuan and Qinling faults (Peltzer et al., 1985; Peltzer and Tapponnier, 1988; Ratschbacher et al., 2003; Zhang et al., 2003; Liu et al., 2013). Figure 2.3 shows an illustration of how the eastward extrusion and the normal faulting at the basin are related. The eastward extrusion is forced by the continental collision between India and Eurasia (Molnar and Tapponnier, 1975; Tapponnier et al., 1982; Tapponnier et al., 2001). The northward advance of the Indian Plate, relative to the Asian continent not only caused the Tibetan Plateau to be uplifted, but also pushed the South China Block (SCB) to the East, creating a large left lateral strike-slip zone in Central China. Perpendicular to the eastward extrusion of the SCB, rifting and severe subsidence occurred around the stable Ordos Block on the North China Block (NCB). Through the complex relation between the tectonic push of the Indian subcontinent and the resulted rifting in northeast China, the

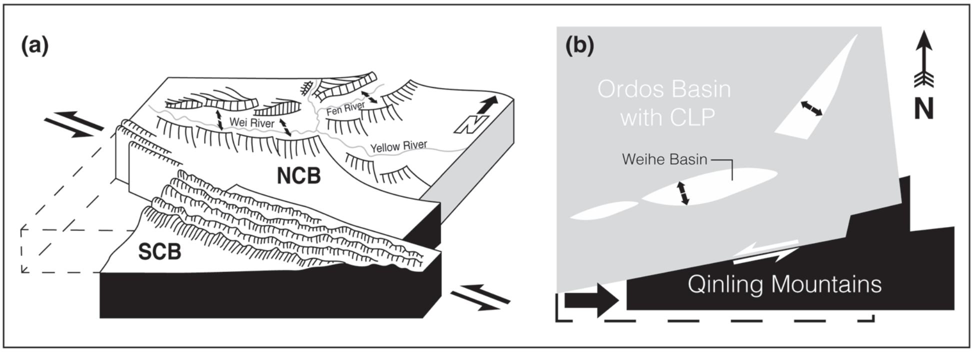

Figure 2.3 - (a) Simplified block diagram showing the relation between the large strike-slip zone in Central China and the formation of the Weihe Rift Basin. **(b)** 2D-overview of this system.

regional tectonics in the Weihe Basin is linked to the large scale uplift of the Tibetan Plateau (Peltzer et al., 1985; Zhang et al., 1998; Ratschbacher et al., 2003; Roger et al., 2011). The rapid extension in the Weihe Basin, recorded at the end of the Miocene, is attributed to a massive uplift event in the northeastern region of the Tibetan Plateau (Liu et al., 2013). This suggests that especially the uplift in this region has a profound impact on the extension rate in the basins around the Ordos Block.

2.3 Hydrological setting

The Weihe Basin is located along the Wei River and the middle reach of the Yellow River. A variety of larger and smaller rivers transport sediments to the Weihe Basin. The Yellow River is with a length of 5464 m, the second largest river of China (Kong et al., 2013b). It originates from the northeastern Tibetan Plateau and makes a wide and characteristic U-bend around the Ordos Block (Fig. 2.4). The river developed this course through the connection of isolated

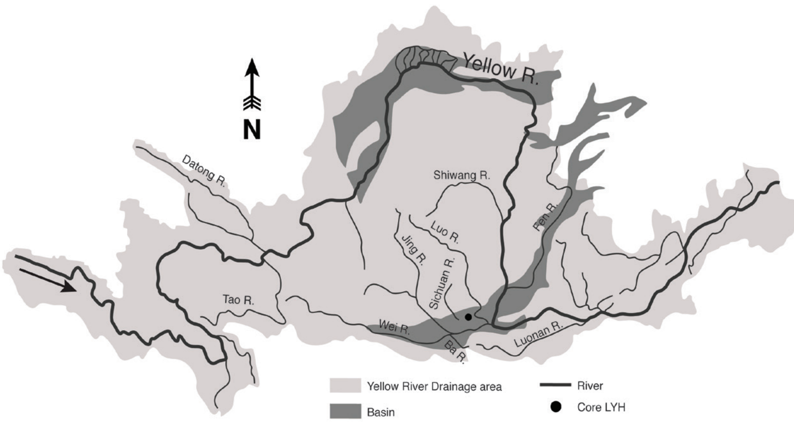

Figure 2.4 - Catchment of the Yellow River, with the Weihe Basin along its middle reaches. The Yellow River enters the basin on the eastern side, but its largest tributary flow axial into the basin. The most important transverse rivers are the Luo, Sichuan and Jing Rivers.

Figure 2.5 - (a) A meander of the Luo River, relative proximal to the drill site of core LYH. **(b)** The Jing River. **(c)** The Sichuan River, which is currently dry and overgrown by vegetation.

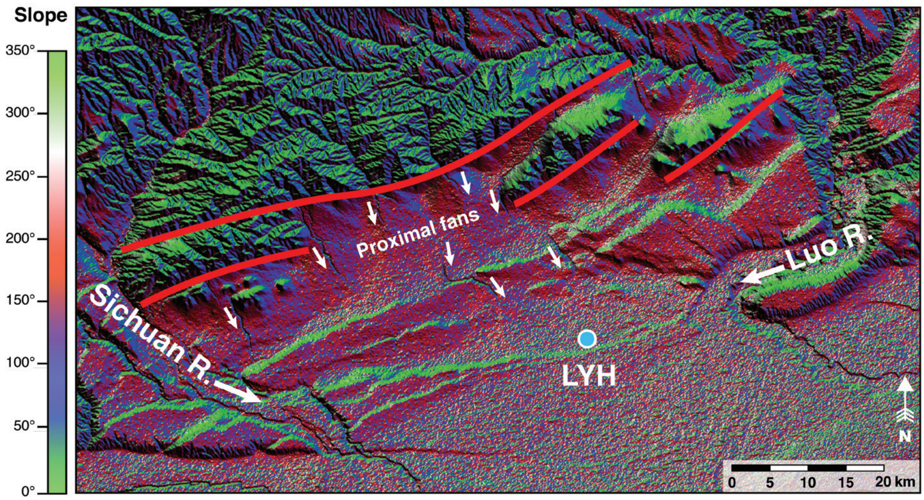

Figure 2.6 - A slope direction map of the northern Weihe Basin. It shows multiple incised gullies in a proximal alluvial fan system. The gullies are indicated by a white arrow next to it. The Sichuan and Luo Rivers drain the CLP from the northwest and northeast respectively. The red lines indicate the position of the BPF. The blue dot highlight the position of core LYH.

fluvio-lacustrine basins and headward erosion, presumably at 1.8 Ma (Harkins et al., 2007; Craddock et al., 2010). After flowing around the Ordos Block, the Yellow River enters the Weihe Basin from the northeast and leaves through the Sanmen Gorge in the southeast. Upon entrance to the basin the river leaves its confinement of the Jinshaan Gorge, which causes the river to spread laterally, creating a wide floodplain. The associated drop in gradient also resulted in massive deposition of alluvium in the eastern part of the basin.

The Wei River also originates from the northeastern Tibetan Plateau and is the largest tributary of the Yellow River, flowing parallel to the orientation of the Weihe Basin. It enters the basin in the western margin to join the Yellow River in the East of the basin, near the city of Fenglingduzhen. It drains an area of approximately 134,800 km^2, which is mostly trough the southern margin of the Weihe Basin. The Wei River valley could be a possible paleo-channel of the Yellow River, running along the axis of the basin (Lin et al., 2001). According to Lin et al. (2001), the Yellow River developed its characteristic square bend (Fig. 2.4) by diverting its course towards the north at Late Miocene-Early Pliocene time.

The Luo, Jing and Sichuan Rivers (Fig. 2.4 and 2.5a-c) enter the Weihe Basin from the North after they drain the CLP. These rivers are fed by numerous smaller gullies and transport large quantities of Quaternary loess as well as underlying Mesozoic rocks to the basin. The Luo and Jing Rivers join the Wei River in its downstream reaches, while the Sichuan River currently has no water (Fig. 2.5c). Figure 2.6 shows a slope direction map of the northern Weihe Basin, indicating that between the Sichuan and Luo Rivers there are many incised gullies. They cut through proximal alluvial fans originating from the Beishan Mountains. A field survey in one of these valleys revealed that these gullies transport reworked loess (Fig. 2.7). The gully contains shallow channels filled with reworked eolian silts (Fig. 2.7b), soils that developed on the flanks of gullies (Fig. 2.7c) and washed out carbonate nodules (Fig. 2.7d), which is an indication for soil reworking processes.

Another important river that enters the Weihe Basin is the Ba River, that originates from the Qinling Mountains in the Lantian district. This is a relative short river, but with a different sediment load (much coarser sediments) as it does not erode the easily erodible loess on the CLP.

2.3.1 Fluvio-lacustrine evolution around the Weihe Basin

Geological sections in the southeastern Weihe Basin show signs of fluvio-lacustrine deposition (Fig. 2.8). The fluvio-lacustrine sequence associated with the lake is composed of the lower gray-colored Youhe Formation and the upper earth-colored Sanmen Formation. The latter show signs of strong fluvial influence with thick coarse grained breccia over finer grained lacustrine deposits (Fig. 2.8b) or a channel infill with massive erosional contact and cross-bedding structures (Fig. 2.8c). The presence of thick lacustrine deposits in the Weihe Basin suggests the former existence of a (paleo-) lake (Sanmen Lake) in the Weihe Basin. The lake would have extended 400 km westwards from the Sanmen Gorge (Jiang et al., 2007), which means that it covered the core site as well (Fig. 2.9). The cut-through of the Sanmen Gorge resulted in the drainage capture of the lake and the final integration of the Yellow River (Kong et al., 2013b). The development of the Weihe Basin must therefore have exerted a significant impact on the evolution of the Yellow River. However, the timing and cause (climate or tectonic) of the disappearance of the lake remains subject for debate.

Thermoluminescence dating on fluvial sands in the Sanmen Gorge yielded a relatively young age of approximately 0.15 Ma for the drainage of the Sanmen Lake (Wang et al., 2002; Jiang et al., 2007). However, based on analyses on fluvial terraces, Pan et al. (2005a; 2005b) argue that this event took place at around 0.9-1.2 Ma, while Kong et al. (2013) concluded that the drainage occurred between 1.3-1.5 Ma. Hu et al. (1993) even argued that the inception of the Sanmen Lake took place at an Early Pleistocene age.

Terrace staircases have been studied in and around the Weihe Basin in order to provide insights in the fluvial response to extrinsic forcing. The fluvial landscape responds to Quaternary climate change superimposed on tectonic offset (Pan et al., 2009; Pan et al., 2010; Hu et al., 2016). The incision of the Yellow River though the Jinshaan Gorge (north of the Weihe Basin) appears to have started at 3.7 Ma due to uplift of the Ordos Block in response to the

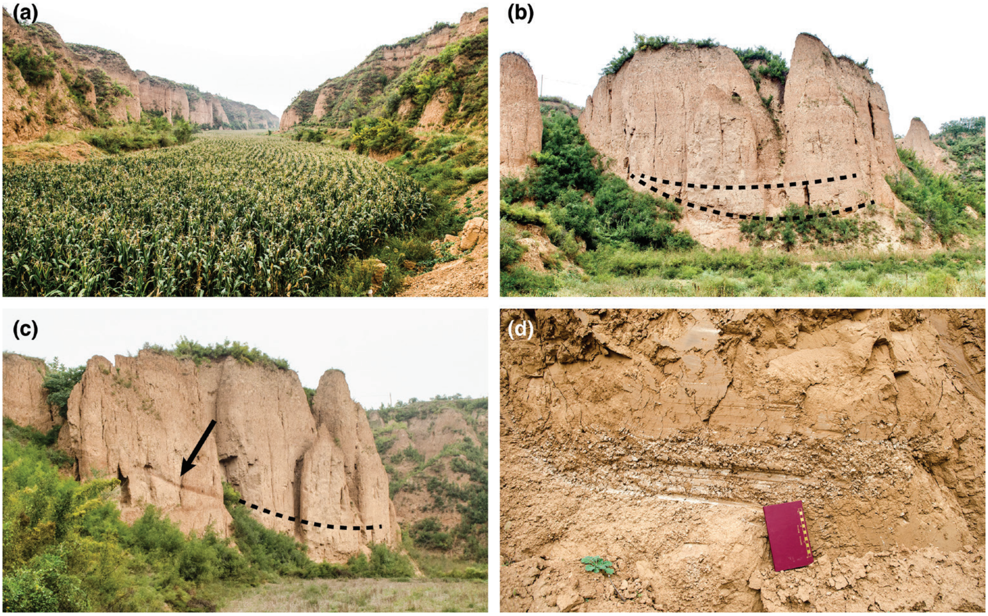

Figure 2.7 - Intense fluvial erosion of the CLP directly north of the drill site of core LYH-1 **(a)** A deeply incised gully at the southern margin of the CLP and directly north from core LYH-1 **(b)** A loess filled trench, flowing axial to the main gully depicted in 2.6a **(c)** Fluvial eroded paleosols (darker bands). The upper (younger) soils points convergent to the older soil as a result of gully erosion. **(d)** Eroded and washed out carbonate nodules.

Figure 2.8 - Geological sections in the southeastern part of the Weihe Basin. **(a)** Fluvio-lacustrine deposits, characterized my multiple gray colored bands (Youhe Formation). **(b)** Erosive contact of coarse grained breccia overlying fine grained deep reddish lake deposits (Sanmen Formation). **(c)** Channel fill deposit, containing cross-bedded sands.

growth of the Tibetan Plateau (Pan et al., 2010). The incision of the Yellow River forced several tributaries to incise in response to the lower base level (Qiu et al., 2014). Individual incision events in the Jinshaan Gorge are associated with crustal extension of the Weihe Basin (Hu et al., 2016). Although multiple terraces were distinguished, the authors report an increased incision rate at 412 ka.

In the eastern Weihe Basin, a shift from aggradational terraces to cut-and-fill terraces was observed later, at approximately 240 ka (Hu et al., 2012). This shift was also dedicated to tectonic influence in the basin. A study on Yellow River terraces near the Sanmen Gorge indicate an even younger geologic event at 150 ka (Zhang et al., 2004). Sun (2005) investigated terraces of the Wei River and distinguished five incision events at 2.6, 1.2, 0.9, 0.65 and 0.15 Ma, occurring in glacial periods. He dedicated these incision events to tectonic activity, related to increased uplift of the northeastern Tibetan Plateau. In addition, studies on terraces on the upper Wei River report increased incision rates at 0.13 Ma (Gao et al., 2008; 2016). Despite a strong influence of tectonic offset on fluvial incision, most studies acknowledge an important role for Quaternary climate transitions on river incision.

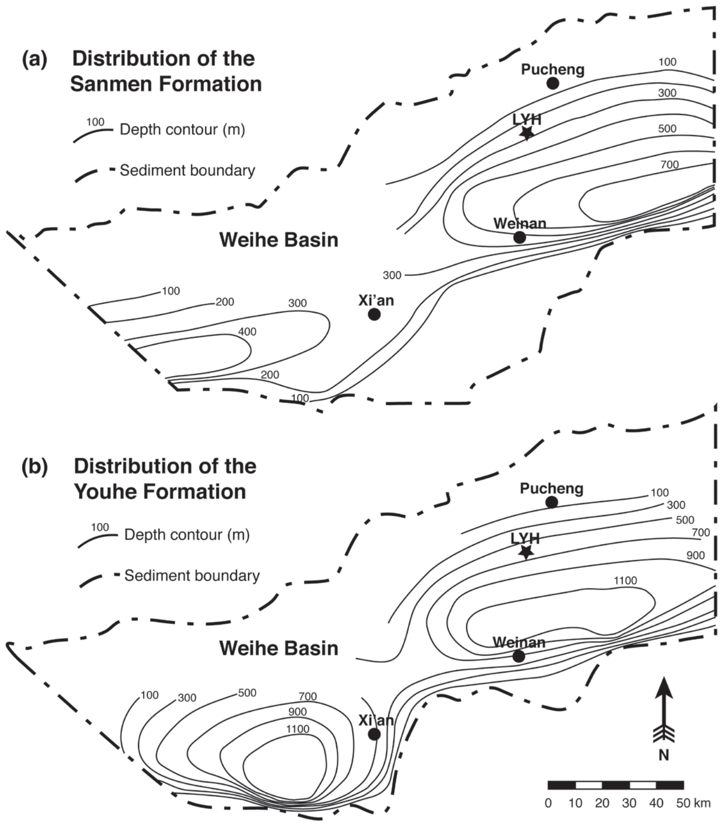

Figure 2.9 - Contour plot of the thickness of the **(a)** Sanmen and **(b)** Youhe Formation. These formations represent fluvio-lacustrine deposition associated with the former Sanmen Lake. Redrawn from Kong et al. (2013).